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A typology for unpacking the diversity of social innovation in energy transitions

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ABSTRACT

Academic research and policy have focused on sustainable energy transitions for addressing the societal challenge of climate change for a long time, but the concept of 'social innovation' has only been recently taken up. This concept refers to different social phenomena relating to changes in socio-technical systems. Moving beyond narrow perspectives on social innovation, this article asks how we can capture the diversity of social innovation, taking the example of the energy sector. It proposes a comprehensive typology of social innovation that allows to capture the phenomenon in its empirical diversity, and to more systematically investigate processes of social innovation and their contributions to making socio-technical systems more sustainable. The typology is based on a conceptual understanding of social innovation in energy (SIE) as comprising changing social relations involving new ways of doing, thinking and/or organising energy. It is empirically grounded in mapping and analysing 500 SIE-initiatives across eight European countries. Such a conceptually-informed and empirically-grounded understanding of SIE sheds light on the 'social' as an object of innovation, the agency of a multitude of actors, and the different types of social relations and activities pursued by energy system actors. It also opens the possibility to publicly discuss the diverse social innovations and their interdependencies, (un)desirability, as well as transformative potentials in energy transitions.

1. Introduction

The concept of social innovation has seen a rapid uptake in research and policy in the last decade [1–5]. Many definitions are used, which all converge on taking the social as object of innovation [6–9]. As an innovation category and potential source of solutions to address complex societal challenges, social innovation has also climbed the European innovation policy agenda [10]. It is regarded as a 'driver for change' and as being able to address societal challenges such as an ageing population, growing inequality, climate change, globalisation and digitalisation [11–13]. The German government, for example, considers social innovation as necessary for addressing societal challenges such as those linked to climate protection, sustainability, and energy [14]. These high expectations of social innovation to address societal challenges raise questions about its potential to contribute to societal transitions [4,6].

One of these societal challenges is climate change, for which the decarbonisation of the energy sector plays a key role. In energy research [15–17] and energy policy [18,19], the concept of 'social innovation' has been picked up only recently to denote different social phenomena relating to changes in energy systems. Social innovation in energy (SIE) has been linked to phenomena ranging from community energy [15,20], innovative business models [21], energy sufficiency or saving [22,23], to energy games and green nudging [16]. They are said to cover production and consumption of energy related to heat, electricity or mobility through the engagement of citizens and multiple other actors. While the concept of SIE is taken up, only a handful of studies actually defines or conceptualises it [15–17] leading to a fragmented understanding and underutilised potential. Therefore, this article embarks on a novel conceptually-informed empirical exploration of the diversity of the social as object of innovation in energy, to arrive at a systematic overview of diverse social innovations.

Such a systematic overview can increase our understanding of social dynamics in socio-technical systems by uncovering alternative social relations or practices (rather than technologies) and thereby open up the possibility to publicly discuss their (un)desirability, as well as their

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transformative potential in sustainability transitions. Consequentially, the research question for this article is: *How can we capture the diversity of social innovation?* This article aims to answer this question using the case of the energy sector which is under great pressure to become more sustainable by first, outlining our understanding of SIE and second, developing a conceptually-informed typology of SIE that is empirically-grounded in the mapping and analysis of 500 SIE-initiatives across eight European countries.

We structure this article as follows. First, we provide a background to the existing work and understandings of SIE (Section 2). We then introduce our understanding of social innovation and conceptualise a way to delineate diverse SIE that can be used to develop a typology (Section 3). Next, we introduce our methodological design for arriving at a typology of SIE (Section 4). This is followed by our results, specifically the characterisation of the different types of social innovation (Section 5). We discuss the limitations, benefits and potentials of the typology and conclude the article with reflections on future research avenues (Section 6).

2. Taking stock of social innovation in energy

Understandings of social innovation diverge in many aspects. However, they share a focus on 'the social' as object of innovation, e.g. social organisation, relations or practices, often considered to address societal problems or satisfy needs [1,6,8,24]. Research on energy systems and energy transitions has focused on the social dimensions of energy systems for a while, including politics, policy and governance as well as (user) behaviour, markets or industrial processes [25,26]. Only more recently has it taken up the term 'social innovation' explicitly to refer to innovations in these social dimensions. To date, there is only a handful of studies concerned with conceptualising social innovation in energy (SIE) [27]. In the following, we highlight several observations on how SIE has tended to be conceptualised so far, to then point to the need for a systematic understanding of diverse SIE.

Firstly, the concept of social innovation in general is often referred to in an instrumental and normatively laden connotation, as a tool through which society can be shaped in certain directions (as argued by [28–30]) – as it has been introduced by the Bureau of European Policy Advisors (BEPA) in 2010. Building on this definition, Hewitt et al. [15] for example define SIE as "*reconfiguring of social practices in response to societal challenges, with the aim of improving societal well-being through the engagement of civil-society actors*". Also Hoppe and de Vries [16] define SIE building on the BEPA definition as "*innovations that are social in their means and contribute to low carbon energy transition, civic empowerment and social goals pertaining to the general wellbeing of communities*". In such conceptualisations, SIE is a tool through which to reach social goals in energy system change. Hiteva and Sovacool [21] for example analyse how social innovations can support embedding energy justice in business model innovation.

Secondly, initial studies using the term social innovation in energy focused on renewable energy production and distinguished between energy collectives (e.g. collective purchasing, co-housing), local production of energy, district and neighbourhood energy systems, working with smart metres, general energy services and energy efficient mobility [31]. This followed a trend that had studied community energy through the lenses of grassroots innovation [32]. These bodies of literature frequently linked social innovation to bottom-up activities and often referred to social innovation to denote innovations that are not primarily technological, or that are an extension of technological innovations [33,34]. An exception is the study by Hewitt et al. [15], who provide a historical account of community energy as social innovation in which they differentiate between types of organisational actors in community energy, such as projects by local governments private companies or renewable energy cooperatives. There are also other publications that develop typologies of bottom-up energy actors [35–38] or renewable energy projects [39–41].

Thirdly, scholars have empirically explored social innovation and in doing so covered a range of phenomena. Hoppe and de Vries [16] analysed the 20 articles to their journal volume on 'Social Innovations in the Energy Transition', and differentiated between six major thematic areas of SIE including: "*1) technological innovation leading to new market models, actor configurations, and institutional settings creating room for social innovation; 2) new governance arrangements; 3) community energy, its impact, implications, and social incentives and policy to empower it; 4) new participative research approaches to test and learn from livings labs and best practices; 5) 'green nudges' to stimulate behavioural change; and 6), serious energy games*". Others, such as Lorek and Spangenberg [22] link energy sufficiency in housing to social innovation, which they seem to understand as the collaboration of multiple actors in new ways. While Hölsgens et al. [42] stretch it towards covering a broader climate change agenda including food waste and recycling.

This broadening out of the understanding of SIE has been taken up by a group of scholars concerned by the current narrow and instrumental understanding [17]. From a critical reconstructive perspective, they bring forth the following arguments to open up the understanding SIE. Firstly, *SIE is multi-directional*. Rather than equating social innovations with their desired outcome and thus treating them as societal improvements that are inherently good, the normative complexity of social innovation and its multi-layered ethical implications should be starting points [6,24,28]. Second, *SIE can originate from and involve actors from multiple societal spheres* (e.g. civil society, local government, energy businesses). Rather than limiting social innovation to grassroots innovation or citizen initiatives, social innovation can involve and originate from different institutional contexts and actors, including civil society, state or market - thus in every sphere of society [43,44]. Third, *SIE shows the interplay between the social and the material*. Rather than confining social innovation to immaterial aspects only, or juxtaposing it with technological innovation, social innovation can be regarded as an analytical entry point that increases our understanding of the interplay of social and material elements – for example on PV panels and related business models or organisational forms. Fourth, *SIE as experimentalism*. Rather than considering social innovation as predictable and direct effect of policy, a broadened understanding considers how policy can better enable co-creation, experimentation and transformative governance involving changes in relations between actors and institutions.

There is thus an increasing need and interest for understanding SIE, both conceptually and empirically, and relating it to energy system transformations. Building on existing work [4,16,17,31], our aim is to create a systematic typology of social innovation that is both conceptually-informed and empirically-grounded and encapsulates diverse SIE.

3. Conceptualising and defining social innovation in energy

Before starting to develop this typology of SIE, we need to clarify our conceptualisation of the phenomenon. To this end, we draw on sustainability transitions research [45–47], and specifically its socio-institutional perspective [48], which allows an investigation of the dynamic interactions between social innovation and broader institutional dynamics towards transformative change [6,7,28]. Building on the work around transformative social innovation [4,6,49] that bridges sustainability transitions research with social innovation research, we define *social innovation in energy* (SIE) as (combinations of) ideas, objects and/or activities that change social relations, involving new ways of doing, thinking and/or organising energy. This includes ideas, objects and/or actions related to energy consumption (also efficiency, savings), storage, trading, transmission/distribution, and/or production. For example, a citizen assembly on the reduction of greenhouse gas emissions changes the relations between a government and its citizens who work in cooperation towards a shared goal through an innovative format of citizen engagement. Such SIE can be transformative, and thus address societal challenges, to the extent that it challenges, alters and/or

replaces dominant societal institutions in the process [4,6]. A transformative social innovation perspective thus recognises that there is a need to focus on processes of social innovation as 'innovation journeys' rather than as static entities.

We also differentiate between social innovation actors and the social innovation that they want to bring forth, for example an energy cooperative from 'producing and consuming renewable energy locally based on cooperative principles' (cf. [28]). Doing so allows to firstly, consider the distributed nature of agency in processes of social innovation, and thus how energy cooperatives, in working towards local cooperative based energy production, are embedded in a web of actors and structures mediating their efforts [50,51]. Secondly, to differentiate between the various social innovations that an energy cooperative, as social innovation actor, could be driving – next to local cooperative based energy production that could include peer-to-peer learning on energy sufficiency or crowdfunding campaigns. Finally, it helps to decouple the outcomes of social innovations from the intentions of the involved actors – whether or not the outcomes of a social innovation are desirable is then not predefined but depending on the observer and normative perspective taken. Thus, whether the production of locally produced renewable wind energy is considered as something desirable depends on the perspective of the evaluator of this outcome.

The understanding of (transformative) SIE adopted in this article thus builds on the critical reconstructive SIE perspective [17] outlined under Section 2 and a transformative social innovation perspective [4,6] as outlined in the previous paragraphs, while it is the first to operationalise a relational understanding of social innovation in the energy domain. For the remainder of this section, the focus will be on this further operationalisation by zooming in on the operationalisation of the three elements of our SIE definition: 1) the (combinations of) ideas, objects and/or actions *as* socio-material configurations, 2) the changes in social relations *as* social interactions and 3) the new ways of doing, thinking and/or organising *as* manifestations. We expand on each of these elements in the following sub-sections.

3.1. Socio-material configurations

Each social innovation can be identified through its *socio-material configuration*, i.e. its 'combinations of ideas, actions and/or objects' – where one of these elements suffices, but seldom comes on its own. To this end, we build on an operationalisation that was developed by Pel et al. [52] when analysing renewable energy prosumerism as social innovation. They consider:

- *ideas* to include narratives, rules, knowledge and expectations;
- *objects* to relate to technologies, infrastructures, natural resources;
- *actions* to relate to practices, routines and behaviour.

Taking 'cooperative heat provision' as an example of a socio-material configuration, it includes *ideas* about the possibility to organise heat provision in a decentral, small-scale and community-owned manner, *objects* can refer to the physical networks, and *actions* include attending to heat generators, and producing/distributing heat. In contrast to how technological innovation is understood, social innovations can refer to 'ideas' (such as the idea of a 'decentralised energy system') and indeed such immaterial aspects are characteristic to social innovation [53]. Ideas in this vein are regarded as 'social facts' that are considered to be true and therefore guide behaviour ([7] drawing on [54]). According to our definition of social innovation, each of these configurations of ideas, objects and/or actions can be considered as 'socially innovative' to the extent that they imply/demonstrate a change in social relations associated with new ways of doing, thinking and/or organising energy.

3.2. Changing social relations as social interactions

'Social relations' refers to the relations or interactions between actors in society, and there are certainly various ways to think about and define social relations. In sociology, social relations between actors are often described by referring to the way actors interact with one another such as cooperation, conflict or coercion, exchange (incl. reciprocity, transaction), or accommodation [55,56]. Sociologists thus use social interactions as proxy for describing social relations. For our purpose of systematically exploring the diversity of social innovations, we build on Brinkerhoff et al. [55] to differentiate between the following four types of social interaction that are a proxy for describing social relations:

- "***Cooperation*** *is interaction that occurs when people work together to achieve shared goals*" [55]. People are more likely to cooperate when they face a common threat, share a common identity, belong to a community or when they gain economically. While cooperation is teamwork, exchange is a trade. Cooperation, for example comes to the fore when members of an energy cooperative work towards the shared goal of an energy system based on RE.
- "***Exchange*** *is the voluntary interaction from which all parties expect some reward*" [55]. It concerns the trade of tangible or intangible benefit (e.g. a subsidy where a community energy initiative receives money and produces renewable energy in return). Such interaction is reciprocal in that the giver expects something in return.
- "***Competition*** *is a struggle over scarce resources that is regulated by shared rules*" [55]. People are more likely to compete if their respective goals are mutually exclusive, or when they experience a scarcity of resources. Such competition is regulated by shared rules. An example is competitions organised between user groups to facilitate energy savings.
- "***Conflict*** *is a struggle over scarce resources that is not regulated by shared rules, it may include attempts to destroy, injure, or neutralise one's rivals*" [55]. People enter conflict when there are no shared rules to regulate struggles – a common enemy can enhance the solidarity within a group. This can relate to subversive activities that directly impair energy generation such as squatting power plants.

These four types of social interaction are not mutually exclusive but exist next to each other. For example, social interactions in energy system as regulated markets are based on exchange (e.g. between producers and consumers of energy) or on competition (e.g. between producers in the energy market), but we also see cooperation (e.g. between grid operators and energy producers) and conflict (e.g. between governments and citizens regarding the choice for certain energy sources). This distinction between the four types of interaction allows us to describe certain socio-material configurations (e.g. cooperative heat production) along the types of interaction that are characteristic of them (e.g. cooperation) and think through changes of social relations and their characteristics in energy transitions (e.g. changes between neighbours, with new roles for energy cooperatives vis-à-vis grid operators or municipalities) – however, it is only through empirical contextualisation that one can assess the extent to which social relations (i.e. types of interactions) are changing.

3.3. New ways of doing, thinking and/or organising energy as manifestations

The suggested definition of social innovation also distinguishes between new ways of doing, thinking and/or organising. Based on [6,57,58], we further operationalise these as follows:

- **Doing:** 'practices related to energy technologies and the physical composition of the energy system', such as energy production, consumption or storage.
- **Organising:** 'governance and organisational structures within initiatives and within the energy system', such as deliberative principles to arrive at shared climate goals, or structures for networking and knowledge exchange.

- **Thinking:** 'forms of knowledge and normative framings including values and perceptions', such as expert knowledge on battery technologies or on energy regulations.

These new ways of doing, thinking and/or organising describe the ways in which socio-material configurations empirically manifest in the energy sector, for example, energy cooperatives organise themselves by giving each member one vote, put solar PV on roofs and train neighbours in attending to these; i.e. they empirically manifest new ways of doing, organising and thinking about energy. We therefore refer to these new ways as 'manifestations'. Rather than referring to manifestations that are *entirely new*, 'new' here refers to an array of phenomena, including the integration of new elements in existing contexts and new combinations of existing elements, but also reinventions, restoration or reassertion of practices that differ significantly from the mainstream [59–61]. A classic example is the organisational form of the cooperative to secure energy production and supply, which has a long history in many European countries [62,63].

This conceptualisation and definition of SIE as socio-material configurations that change social relations and involve new ways of doing, thinking and/or organising energy, will guide our systematic exploration of the diversity of SIE and the development of the typology of SIE in the subsequent sections.

4. Methodology: creating a typology to study diverse social innovation in energy

The development of the typology of social innovation in energy (SIE) (cf. [64,65]) was done in iterations between conceptual considerations (see Section 3) and empirical grounding i.e. mapping of 500 SIE-initiatives across eight European countries. Drawing on Kluge [66], we developed the typology in five phases: 1) Development of our conceptual variables (see Sections 3 and 4.1), 2) mapping of SIE-initiatives and their SIE in eight European countries (Section 4.2); 3) synthesis of SIE-initiatives and grouping of SIE (Section 4.3); 4) analysis of empirical regularities, meaningful relationships and type construction (Section 5.1); and 5) characterisation of the constructed types (Section 5.2). See Fig. 1 for an overview of the research process.

4.1. Conceptual variables for SIE typology development

Following Collier et al. [67], typologies are made of variables that are cross tabulated. The authors distinguish between four basic elements of typologies. Firstly, there is an overarching concept that the typology will investigate – SIE in our case. Secondly, two (or more) variables along which the overarching concept can be described or explained form the rows and columns of a matrix. Our variables are '*social relations as social interactions*' and '*manifestations as new ways of doing, thinking and/or organising energy*'. Thirdly, a matrix is created using the variables and their expressions (e.g. high/low) – this represents the property space of the typology. We constructed a matrix along the expressions of our two variables, namely four expressions for 'social relations' (cooperation, exchange, competition, conflict) and three expressions for 'manifestations' (doing, thinking, organising). Finally, each of the cells of the matrix provides one of the conceptually-informed 'types' of the typology – in our case the typology matrix differentiates between 12 cells. Operationalising this along our conceptual variables, which have been outlined in more detail in Section 3, provides us with the typology matrix visualised in Table 1.

Each of the cells stands for one type of socio-material configuration (i.e. a specific (combination of) ideas, objects and/or actions) that involve a specific kind of social relation (as expressed through different types of social interactions) and a manifestation (as expressed through ways of doing, thinking or organising energy). An empirical example for 'cooperation/doing' could be the development and installation of PV panels on schools by an energy cooperative, and for 'competition/organising' the organisation of competitions between user groups facilitating energy savings. However, at this stage, the typology could also be applied to other domains such as food or housing since it is not yet specific to the energy domain. It is through grounding the typology empirically that it will become a typology of SIE – this is the next step of typology development.

4.2. Mapping of SIE-initiatives

Starting from the definition and conceptual understanding of social innovation as outlined under Section 3, we embarked on an explorative and iterative process of operationalising and mapping SIE. The mapping aimed to identify SIE-initiatives that empirically manifest as diverse SIE and concentrated on five European countries: the United Kingdom, Germany, Switzerland, Poland, France, and one region: Benelux (consisting of Belgium, the Netherlands and Luxembourg) (see Table 2) [68]. These countries were selected for covering varying contexts for SIE. The relevant dimensions of diversity are grounded in (1) findings on important contextual factors that influence SIE including carbon intensity, the degree of liberalization of the energy market, policy attention towards SIE, history and culture, and the level of technological innovation stimulating SIE [31,69]; (2) researchers experience in working on SIE, and (3) the national implementation of EU energy goals.

We aimed to map approximately 80–100 SIE-initiatives in each of the five countries and the Benelux region where this was feasible. This number was considered to allow for a robust basis for the development of a typology since it meant that also in countries with higher diversity of SIE a point of data saturation could be reached. In total, we mapped and analysed 500 SIE-initiatives across the eight countries. The considerable discrepancy in the amount of SIE-initiatives mapped for Luxembourg and Belgium is due to the fact that we approached the Netherlands, Luxembourg and Belgium as one region (Benelux) and focused on those initiatives whose information was available in either Dutch or English.

The mapping focused on SIE-initiatives (incl. organisations, platforms, projects) as 'unit of analysis', while we aimed to develop a typology of SIE (thus of socio-material configurations that change social relations and involve new ways of doing, thinking, and/or organising). We thus took actual initiatives as pragmatic starting points, and then added an analytical step of formulating the SIE that each of the SIE-initiatives was engaging in (see Section 4.3 for the explanation of this step).

The SIE-initiatives were mapped and selected between September 2019 and January 2020 by an inter- and transdisciplinary group of university researchers and urban civil servants[1] allowing for diverse interpretations of what SIE could mean to start with. Sub-teams were formed for each country and the Benelux region. The mapping process was informed by the conceptual work outlined under Section 3, and is documented in detail elsewhere [70,71]. The following outlines its main elements:

- During a **focus group workshop of the mapping team** (October 2019) the definition of SIE as well as five examples of SIE suggested by each of the country teams were discussed. This workshop aimed at establishing a common understanding of what was to be considered (or not) as SIE and SIE-initiative for the upcoming mapping process.
- **Mapping guidelines** (July–October 2019) were drafted to guide the mapping that formed the input to the focus group workshop. They were finalised after that workshop and outlined the sampling principles and strategy focused towards exploring the diversity of SIE-initiatives. The guidelines also presented the mapping categories to be filled in for each SIE-initiative.

[1] This group collaborated in the context of the EU-funded 'Social Innovation in Energy Transitions' (SONNET) research project into the diversity, processes and contributions of social innovation in energy.

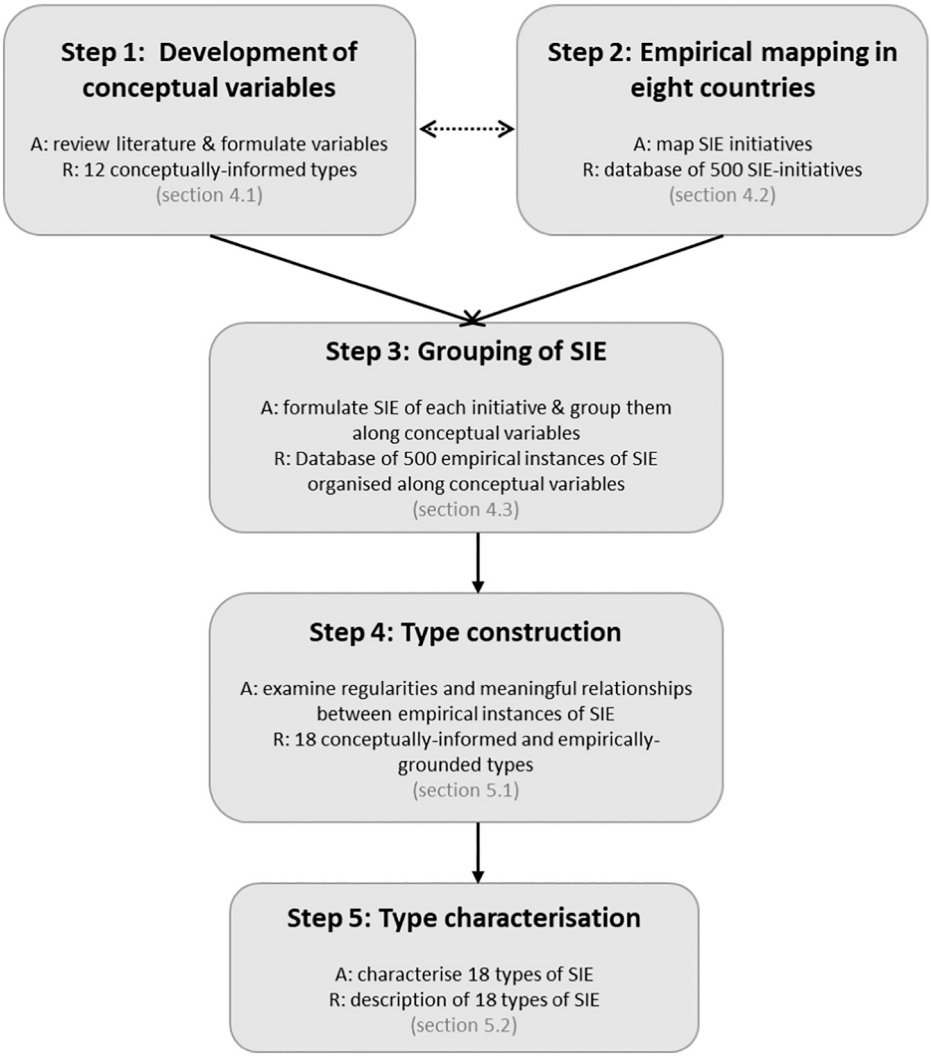

Fig. 1. Illustration of the research process (A = activities; R = results).

Table 1
Typology matrix of conceptually-informed types.

		Social interaction			
		Cooperation	Exchange	Competition	Conflict
Manifestations	Doing	1: cooperation/doing	4: exchange/doing	7: competition/doing	10: conflict/doing
	Thinking	2: cooperation/thinking	5: exchange/thinking	8: competition/thinking	11: conflict/thinking
	Organising	3: cooperation/organising	6: exchange/organising	9: competition/organising	12: conflict/organising

Table 2
Number and geographical spread of mapped and analysed SIE-initiative.

Country	SIE-initiatives mapped (#)
BENELUX	
Belgium	21
The Netherlands	72
Luxembourg	15
United Kingdom	85
Germany	79
Switzerland	79
Poland	70
France	79
Total	*500*

- The **mapping categories** were meant to capture general information about the SIE-initiative (e.g. name, website, year initiated, country), and more specific information regarding their position (e.g. aims, perceived issues of current energy system, ways to address them) and their ways of doing, thinking and/or organising (e.g. most prevalent energy activities, description of what the SIE-initiative is about). Each of the mapping categories was operationalised through formulating a definition and an empirical question. Each category also included an instruction on how to answer it (e.g. drop-down, free text) and an indication of its relevance for the analysis. The main sources for the mapping were the websites of the initiatives that were translated into English using freely available web-based translation services.

- **Iterative feedback** was provided during the first few weeks of mapping SIE-initiatives. Three researchers regularly examined the entries of the country teams to adjust/clarify some of the mapping categories.
- **Intermediate analysis** (November 2019) after about half of the targeted sample size of SIE-initiatives had been mapped per country. The result of this analysis led to suggestions for further diversification of the search for each country, and a final set of mapping categories. The intermediate analysis also allowed to start systematically identifying and categorising the activities, aims, etc. of SIE-initiatives along the two variables i.e. social interactions and manifestations.

4.3. Empirical grounding of SIE-types

Once the mapping was finished, we analysed the full set of SIE-initiatives [68] in an iterative way – meaning we went back and forth in the analysis with a focus on diversity of SIE and consistency of analysis steps [70,71]. It is important to keep in mind that the SIE-types are not descriptions of reality but rather constructs which can be drawn upon as devices to understand diverse SIE (see Webers work on 'ideal types' [72]). In the following steps, we try to be as transparent as possible to describe this process of creating the constructs and our decisions taken along the way.

Based on the information for each SIE-initiative, we started with translating the database of SIE-initiatives into a database of empirical instances of SIE by formulating the combination of ideas, objects and/or actions (i.e. socio-material configuration) that change social relations and involve new ways of doing, thinking and/or organising energy that this SIE-initiative worked on. For example, Bristol community energy fund drives the SIE that we formulated as 'local governmental fund for community energy initiatives' (see Table 3, third column for more examples). Since SIE-initiatives might work on several socio-material configurations, we needed to decide on how to address this multiplicity. Rather than formulating all socio-material configurations that an initiative worked on, we focused in first instance on those ideas, actions and/or objects that could be considered the most dominant based on the available data on the aims, activities and goals of the SIE-initiatives. However, in instances where such 'dominance' could not be clearly established, we recurred to our goal of exploring the diversity of SIE and formulated those socio-material configurations that were not yet covered in our sample.

Subsequently, we categorised the SIE and the corresponding SIE-initiative along the two typology variables (see Table 3, fourth and fifth column for examples). For the social relations as social interactions variable, we decided to identify the type of interaction that was most dominant in how the initiative was organised (e.g. legal form) and/or in how it presented itself (e.g. in who were considered beneficiaries, and the activities through which it aimed to address challenges in the current energy system). This does however not mean that the other forms of social interaction cannot be identified, rather that these were not considered 'dominant' during analysis i.e., not representing the initiatives core aims and/or activities. For example, the SIE-initiative 'Student Switch Off' works on the SIE 'competition between user groups facilitating energy savings', and due to its appeal towards competitive behaviour was defined as 'competition'. However, it can also show elements of cooperation (if e.g. students work in teams towards decreasing energy consumption) or exchange (if e.g. students meet to exchange insights and learn from one another on how to save energy). Still, Student Switch Off describes themselves on their website to be an "inter-halls sustainability competition rewarding groups of students who achieve the biggest savings in energy".

For the manifestations variable, we examined the activities that SIE-initiatives engage in, and singled out their 'core' activity (e.g. Student Switch Off's core activity is to organise energy savings competitions to nudge behaviour change of students; i.e. 'organising'). After about half of the targeted sample size of SIE-initiatives per country had been mapped, we identified the core activities of each to arrive at a long list of such activities. In a subsequent step, we grouped these into a short list of several overarching activities per manifestation. We used this list to recode the first part of the sample and to code the remaining sample. This list was refined and eventually led to the overview as presented in Table 4. *Doing* includes activities in close relation to physical aspects of the energy system, such as energy technologies or energy infrastructures – this includes *action against political agenda's* that are expressed by demolition of infrastructure or *storing electricity/heat* by installing batteries. *Organising* includes activities that are about making space and facilitation, such as facilitation of access to knowledge, finance and/or networks, or arrange for a context to allow for new ideas, actions and objects (e.g. behaviour change, framings, technological solutions) to

Table 3
Illustration of the analysis of SIE-initiatives.

SIE-initiative	Country	Socio-material configuration	Social relation	Manifestation
Bristol community energy fund	United Kingdom	Local governmental fund for community energy initiatives	Exchange	Organising: Offering/facilitating financing
Conversations carbone	Switzerland	Civil-society facilitated peer-to-peer learning on reducing emissions	Exchange	Thinking: Transferring knowledge & skills
Jouliette	The Netherlands	Local electricity exchange through locally organised electricity grid	Exchange	Doing: Exchanging electricity peer-to-peer
Vereniging Aardehuis	The Netherlands	Eco-efficient housing and energy prosumerism with sociocratic governance	Cooperation	Doing: Generating electricity/heat (efficiently)
Allianz Atomausstieg	Switzerland	Non-profit pushing for nuclear phase-out	Cooperation	Thinking: Campaigning against political agendas
Convention citoyenne pour le climat	France	Citizen assembly facilitating dialogue on reduction for greenhouse gas emissions	Cooperation	Organising: Constructing a dialogue
POAL (Plateforme opérationelle anti-linky)	France	Civil-society platform against smart metres	Conflict	Thinking: Campaigning against political agendas
Obóz dla Klimatu	Poland	Direct action against human and environmental exploitation specifically new coal mines	Conflict	Doing: Action against political agendas
Zielona Transformacja Śląska	Poland	Network facilitating collaborative dialogue against open-cast mining	Conflict	Organising: Campaigning against political agendas
Instytut Energetyki Odnawialnej (IEO)	Poland	For profit advisory on renewable energy through think-tank	Competition	Thinking: Providing advice
Student Switch Off	United Kingdom	Competition between user groups facilitating energy savings	Competition	Organising: Nudging & facilitating behaviour change
Clean Energy Global	Germany	For-profit leasing business model for batteries	Competition	Doing: Implementing technology-based energy services

Table 4
Operationalisation of manifestations in the energy system.

	Definition	Operationalisation
Doing	Practices related to energy technologies and the physical composition of the energy system	Generating electricity/heat (efficiently) Supplying electricity/heat Using electricity/heat (efficiently) Exchange electricity peer-to-peer Storing electricity/heat Implementing technology-based energy services Installing energy technology Action against political agendas
Organising	Governance and organisational structures within initiatives and within the energy system (i.e. institutions in terms of forms of social organisation or standard operating procedures that shape behaviour and find expression through rules, practices and narratives)	(Facilitating) Networking Providing services Offering/facilitating financing Constructing a dialogue Incubating ideas and solutions Facilitating supply/demand exchanges Nudging and facilitating behaviour change
Thinking	Forms of knowledge and normative framings including values and perceptions	"Raising awareness" about energy Campaigning against political agendas Pushing a framing, discourse or narrative Providing advice Transferring knowledge & skills

(Slightly adapted from [70].)

emerge. Finally, *thinking* includes those activities that focus on putting forth specific framings or knowledge, such as is done through campaigns, certain forms of energy advices or knowledge sharing sessions.

5. Conceptually-informed and empirically-grounded typology of SIE

5.1. Construction of SIE-types

In the last step, we have grouped the 500 empirical instances of SIE along the two variables, which resulted in their classification within the property space of the 12 conceptually-informed types (see Table 1 for the latter). In a next step, the empirical instances within each of the 12 groupings needed to be examined for empirical regularities and meaningful relationships [66]. Within each of the groupings, we analysed the relationships between the empirical instances of SIE and clustered them in relation to their key differences and similarities. The aim being to understand whether they can be meaningfully understood as constituting one type. By way of example, we categorised 48 empirical instances (e.g. 'citizen assembly facilitating dialogue on reduction for greenhouse gas emissions', 'transdisciplinary city lab for decentralised energy system') within the conceptually-informed type 'Cooperation/Organising' and then further analysed and grouped those empirical instances into two meaningfully different empirically-grounded types, namely 'participatory energy dialogues' and 'participatory experimentation and incubation'.

In this process of scrutinising empirical instances for being meaningfully related to one another, we did not reduce the number of types, but rather developed 18 conceptually-informed and empirically-grounded types of SIE. Table 5 provides an overview of these resulting 18 types of SIE.

5.2. Characterisations of SIE-types

Thus, to briefly summarise, we have developed two relevant conceptual variables and a typology matrix of conceptually-informed types of SIE, mapped 500 SIE-initiatives and translated these into empirical instances of SIE. We then categorised these empirical instances along the two variables and grouped them within the conceptually-informed types, before we analysed them for similarities and differences. This resulted in 18 conceptually-informed and empirically-grounded types of SIE. We understand these types as Weberian 'ideal types' useful abstractions for analyses [72]. To be able to draw attention to the differences and linkages between the types, we developed Table 6 that provides a description of each of the 18 types including the main actors driving this innovation. This is followed by our observations on the linkages between the types.

Regarding our **variable 'manifestation'** expressed through new ways of doing, thinking and/or organising energy, the following observations can be made. Firstly, across those SIE-types that manifest mainly in **new ways of doing**, one distinction is between the generation and supply of electricity and/or heat from RES that are either managed by multi-actor stakeholder groups (#1) or managed cooperatively (#2). Next to the more 'destructive' interventions into the energy system through direct action campaign for example through boycotts or occupations (#16), other physical interventions into energy systems include the exchange of electricity locally making use of/building relevant grid structures (#7), the energy-efficient building and renovation of buildings (#3) and the development and implementation of, often technology-driven, new services and business models (#13) for the generation, supply and installation of energy (technology).

Secondly, regarding **new ways of thinking**, we differentiate between those SIEs that are advocating strongly for (#4) (in our sample typically fuel poverty, energy savings or diversity issues) or against

Table 5
Typology matrix of conceptually-informed and empirically-grounded types of social innovation in energy.

		Social relations as social interaction			
		Cooperation	Exchange	Competition	Conflict
Manifestations	Doing	1 Local energy production and consumption 2 Cooperative energy production & consumption 3 Collaborative eco-efficient housing	7 Local peer-to-peer electricity exchange	13 For profit services and technologies	16 Action against specific energy pathways
	Thinking	4 Advocacy for specific energy pathways	8 Energy education 9 Non-profit consulting 10 Peer to peer learning	14 For-profit consulting	17 Campaigns against specific energy pathways
	Organising	5 Participatory energy dialogues 6 Participatory experimentation and incubation	11 Platforms for direct energy transactions 12 Investment and finance mechanisms	15 Energy gamification & nudges	18 Networks against specific energy pathways

Table 6
Description of 18 types of social innovation in energy.

#	Name	Description	Driving actors
Cooperation/doing (n = 102) *involves electricity generation, supply, storage or efficient consumption (i.e.* ***doing****) through the collaboration between actors towards shared goals (i.e.* ***cooperation****).*			
1	Local energy production and consumption	Multi-actor ownership structures and business models for the generation and/or supply of electricity and/or heat from RES.	Public (e.g. governments; municipal-owned utilities) and/or non-profit actors (e.g. NGOs).
2	Cooperative energy production and consumption	Cooperative business models for the generation and/or supply of electricity and/or heat from RES.	Community-led, non-profit energy organisations based on cooperative principles.
3	Collaborative eco-efficient housing	Housing related efficient energy consumption (e.g. renovation, development of housing complexes) in neighbourhoods and communities.	Developers, associations, communities and/or municipalities.
Cooperation/thinking (n = 50) *relates to collective problem or solution framings (i.e.* ***thinking****) pushed by actors collaborating towards a shared goal (i.e.* ***cooperation****).*			
4	Advocacy for specific energy pathways	Advocacy (e.g. campaigns, lobbying) for certain energy pathways	Communities, multi-actor constellations or coalitions with a shared goal.
Cooperation/organising (n = 48) *involves configurations facilitating (i.e.* ***organising****) the 'doing' and 'thinking' by actors collaborating towards shared goals (i.e.* ***cooperation****).*			
5	Participatory energy dialogues	Facilitated dialogues between actors on energy topics (e.g. energy savings, urban climate policies) in their local environment.	Community-led organisations or public actors; often to engage citizens
6	Participatory experimentation and incubation	Facilitated experimentation and/or incubation of ideas and/or technology in multi-actor formats.	Multi-actor constellations incl. research institutes, industry, government, and beyond
Exchange/doing (n = 14) *involves rearranging distribution and electricity grids using smart technology (i.e.* ***doing****) to trade electricity against payment (i.e.* ***exchange****).*			
7	Local peer-to-peer electricity exchange	Local exchange of electricity (often combined with generation, storage) between different buildings making use of smart technology.	Multi-actor partnerships (e.g. households, community, DSO, municipality, energy utility).
Exchange/thinking (n = 131) *relates to the provision of energy-related knowledge and skills (i.e.* ***thinking****) on a non-profit basis against a tangible or intangible reward (i.e.* ***exchange****).*			
8	Energy education	Expert-led, non-profit education and knowledge transfer (e.g. for a, workshops, trainings, or toolkits) about energy topics (e.g. energy savings, renewable energy) and skills (e.g. installing RE).	Diverse actors (e.g. utilities, municipalities, NGOs) often aimed at citizens
9	Non-profit consulting	Non-profit provision of energy-related knowledge and skills for energy topics (e.g. energy savings)	Community-led organisations, municipalities, NGOs
10	Peer to peer learning	Knowledge exchange about energy topics (e.g. CO_2 reduction, RE) in formal or informal, online or offline settings.	Companies, government, non-profits or communities
Exchange/organising (n = 59) *involves configurations facilitating (i.e.* ***organising****) exchanges of tangible and intangible goods (e.g. energy, money) expecting a reward (e.g. RE production, money) (i.e.* ***exchange****).*			
11	Platforms for direct energy transactions	Digital marketplaces and virtual power plants facilitating electricity exchange.	Businesses
12	Investment and finance mechanisms	Subsidies and financial mechanisms (e.g. crowdfunding) from private or public sources facilitating energy generation, supply, storage or savings.	(Local) governments, companies, NGOs, communities
Competition/doing (n = 48) *relates to the generation and/or supply of electricity (i.e.* ***doing****) based on business models to increase competitiveness (i.e.* ***competition****).*			
13	For-profit services and technologies	Novel for-profit services and business models to supply, generate and/or install energy (technology).	Businesses, both established companies and start-ups
Competition/thinking (n = 13) *relates to the provision of energy-related knowledge and skills (i.e.* ***thinking****) on a for-profit basis (i.e.* ***competition****).*			
14	For-profit consulting	For-profit provision of energy-related expert knowledge and skills (e.g. regarding legal, technological or regulatory matters)	Consultancy firms, think-tanks or information platforms with paywalls
Competition/organising (n = 19) *involves facilitating (i.e.* ***organising****) behaviour change and mobilisation through competitive encounters (i.e.* ***competition****).*			
15	Energy gamification and nudges	Behaviour change from engaging in rule-based competitions around a scarce resource (e.g. award, label, certification) on energy topics.	Municipalities and non-profit organisations
Conflict/doing (n = 3) *refers to direct action campaigns against specific energy pathways (i.e.* ***conflict****) that have direct repercussions for the actual generation, supply, storage or efficient consumption of energy (i.e.* ***doing****).*			
16	Action against specific energy pathways	Direct-action campaigns and protests against specific energy pathway intervening in energy generation (i.e. block installations, destroy equipment).	Movements, informal groups and grassroots actors
Conflict/thinking (n = 9) *relates to the creation and pushing of counternarratives (i.e.* ***thinking****) that are explicitly set in opposition to dominant, often governmental, frames (i.e.* ***conflict****).*			
17	Campaigns against specific energy pathways	Different framings against specific energy pathways (e.g. fossil fuels, nuclear or wind) shared through peaceful opposition or campaigns.	Multi-stakeholder collaborations, associations, NGOs and grassroots actors
Conflict/organising (n = 4) *involves configurations facilitating (i.e.* ***organisation****) the organisation or dissemination of direction action campaigns or counternarratives (i.e.* ***conflict****).*			
18	Networks against specific energy pathways	Network structures that facilitate actors to join forces in opposing certain energy pathways.	Multi-stakeholder collaborations, associations, NGOs and grassroot actors

(#17) (in our sample typically nuclear, coal or wind) specific energy pathways through pushing certain framings, and thereby express different types of interaction (cooperation vs. conflict). While the difference between advocating for or against pathways can be differentiated in terms of SIE, SIE-actors often engage in both: framing what they want to phase out and what they want to embrace. Rather than on

certain framings, other types focus on knowledge transfer and exchange either for-profit (#14) or non-profit (#8, #9, #10). For the latter, those who provide knowledge transfer and exchange expect a reward (that can be tangible or intangible, e.g. changing energy consumption behaviour) in return. While 'energy education' (#8) and 'non-profit consulting' (#9) concern expert led knowledge transfer, where there is a clear hierarchy between the tutor and the pupil, 'peer to peer learning' (#10) is about knowledge exchange between peers.

Thirdly, we distinguished different types of SIE that involve **new ways of organising**, which in turn often facilitate new ways of thinking or doing. Energy generation, supply, storage, exchange and/or savings are for example facilitated through 'participatory experimentation and incubation' (#6), 'platforms for direct energy transactions' (#11) or 'investment and finance mechanisms' (#12). This facilitation is done in very different ways, e.g. incubating smart neighbourhoods or crowdfunding wind energy parks or matching producers and consumers of renewable energy. New framings and knowledge are being facilitated for example through 'participatory energy dialogues' (#5), while deliberation about positioning and behaviour is facilitated through 'energy gamification and nudges' (#15) or 'networks against specific energy pathways' (#18). Additionally, the SIE-types under 'organising' are facilitating their respective type of interaction; for example, 'exchange' of energy is facilitated by 'platforms for direct energy transactions' (#11), while 'cooperation' among actors is facilitated by 'participatory energy dialogues' (#5). These dialogues (#5) focus on deliberation and shared discourses, while 'participatory experimentation and incubation' (#6) focuses on peer-to-peer learning to catalyse and/or accelerate energy innovation, or to test and/or demonstrate technical or social energy experiments (i.e. for realising new ways of 'doing' for SIE-types #1-4). Many of the SIE-types under 'organising' facilitate the emergence of novel actor constellations (#11, #12, #18, partly #15) or their actual collaboration as a learning process (#5, #6, partly #15, #18), others are more about facilitating such new actor constellations (#12, #18, but also #5, #6).

Regarding our variable '**social relations expressed through social interactions**', our mapping, and arguably the diversity of our typology shows that all forms of social interactions (i.e. cooperation, exchange, competition and conflict) can be observed. It is important to point out that the boundaries between cooperation, exchange, competition and conflict are more fluid. Although energy systems are still set in market economies, SIE-actors, due to often not being profit driven, change existing processes and distribution of outcomes in ways that diversify social interactions between energy actors, frequently emphasising elements of cooperation and exchange. In addition, what becomes apparent is that the 'driving actors' are often made up of multi-actor collaborations where different 'normal' ways of interacting (e.g. competition or cooperation) might meet and with it different ways of doing, organising and thinking. More in-depth research is required that examines the social relations within these collaborations to investigate whether actors adapt to a dominant way of working (i.e. competition) and/or whether they get negotiated along the way. Energy transitions seem to be characterised by changes in social relations, but it still is unclear which forms of social interactions will prevail and who will be part of creating and shaping them.

6. Reflections and conclusion

With this article, we aimed to increase our understanding of social dynamics in socio-technical systems, specifically the energy system, by focusing on the creation of alternative social relations involving new ways of doing, thinking and/or organising energy – also referred to as social innovations. We examined how we can capture the diversity of social innovation, taking the example of the energy sector, and for this identified the different types of social innovation in energy (SIE) that currently exist in the 8 European countries investigated. To be able to show the value of such a conceptually-informed and empirically-grounded typology of SIE and how it can be used in future work, we present three reflections on how it opens up the possibility to publicly discuss diverse social innovations and their interdependencies, (un) desirability, as well as transformative potentials in energy transitions. In addition, we reflect upon some of its limitations.

Firstly, the typology moves research beyond the focus on social innovation initiatives, towards social innovations as such. Rather than taking the 'social' as an afterthought of technological innovation, it highlights how energy system transformations are also driven by the changes in the manifold relations and roles of actors and the different activities they engage in. It shows the relevance of a diversity of actors for driving social innovations, such as action-groups, start-ups and civil society actors (e.g. in 'local energy production and consumption', 'action against specific energy pathways'), municipalities and other governmental actors (e.g. 'participatory energy dialogues', 'non-profit consulting', or 'investment and finance mechanisms') and companies of various sizes (e.g. 'collaborative eco-efficient housing', 'peer-to-peer learning' or 'for-profit services and technologies'). However, this typology does not lend itself to pigeonhole actors into particular social interactions and manifestations: while some actor groups might be more prone to act out certain social innovations (e.g. a renewable energy cooperative to engage in 'cooperative energy production and consumption'), our mapping has shown that actors can engage in various socio-material configurations and also combine these (e.g. the same cooperative also raises money through crowdfunding as 'investment and finance mechanism' or provides energy savings advice through 'energy education'). Future research should scrutinise the emergence and development of different types and associated SIE-initiatives as well as their interdependence. In-depth as well as comparative research between countries or between different types of SIE can uncover differences in social innovation processes, their relation to other forms of innovation and provide insights into supportive (and impeding) actor networks and ecosystems involved.

Secondly, the distinction between different types of SIE is necessary and helpful in exploring different directionalities of SIE and hence of transition dynamics – thus the diversity of underlying normative orientations and future directions [73–75]. These are implicated in the different types of interactions that are put forth. To date, much research and policy focuses on competition (e.g. new business models) and increasingly on cooperation (e.g. community energy), where also our mapping has shown a certain bias towards the latter. Addressing this bias, the typology takes a broader set of four types of interaction as constituent expressions of social relations – and thereby goes beyond a focus on competition and cooperation that could be considered more desirable and established. For example, much existing work has gone into 'cooperative energy production and consumption' that pursues specific stands for working together towards a shared goal whereas other types have been more neglected. Each type brings along underlying ideas about future energy systems, actor constellations, forms of participations, beneficiaries and decision-makers. The typology makes such characteristics of diverse SIE visible and transparent. It thus has the quality to open up discussions regarding the desirability or undesirability of certain innovations in relation to public values such as affordability, reliability, sustainability and accessibility of energy.

Finally, the typology leaves open the question of the extent to which certain socio-material configurations are innovative and/or even transformative in a specific context – it considers these as questions to be answered through subsequent empirical research on social innovation and energy transitions. The typology can be a useful heuristic for thinking about the different ways that social innovations not only change social relations but transform energy systems. This could be based on looking at the transformative ambitions (or not) across several SIE-initiatives i.e. goals and aims that make up the different types and transformative potentials (or not) by exploring the extent to which and the ways through which social innovations are challenging, altering and/or replacing dominant institutions [4,6]. Subsequent empirical

research can show which types do have a higher transformative potential and their characteristics e.g. competition or cooperation-based ones. The different types also show that energy systems are being reconfigured in very different ways: through building alternatives (e.g. renewable based and cooperatively managed energy production) or through stopping existing ways (e.g. campaigns against coal-based energy pathways) or a mixture of both. These ways of doing are more often build on multi-actor collaborations rather than a specific actor group i.e. community energy organisations.

The aim to develop a typology of SIE, representing diverse SIE was always going to be an ambitious undertaking. Seeing that we mapped SIE-initiatives from eight European countries and sampling for diversity has meant that we have been able to cover diverse SIE. Still, future studies are needed to verify and possibly expand on the typology considering that SIEs still emerge and develop over time. In addition, it is important to keep in mind that these are 'ideal types', which means they are constructs based on our empirical and analytical work. To be able to develop the types, we mainly considered the 'core' (rather than all) aims and activities of the SIE-initiatives – which involved a process of interpretation on our part. We felt that this step was necessary to derive distinct types through a transparent process. Nevertheless, future work could introduce this diversity in aims and activities to enrich the typology.

Our typology is therefore but a start to be able to discuss systematically the social dimensions in energy and their intertwinement with technological dimensions. Overall, it sheds light on the different changes in social relations as social interactions and the multitude of actors that come into play and/or need to redefine their roles and activities in energy transitions. In addition, what emerges are the diverse directions being pursued as well as the transformative potentials and strategies implied. To live up to their potentials regarding energy system transformations, social innovations do need supportive ecosystems, that are different from those for technological innovation. Taking the typology as a heuristic, innovation and energy policy can create favourable framework conditions for certain related or interdependent types of social innovation, take informed decisions regarding the effectiveness and mainstreaming of diverse social innovations, and direct policy strategies and measures that address specific challenges. Moreover, the typology makes it possible to publicly discuss diverse SIE (including their normative orientations and directions) rather than individual SIE-initiatives and decide on what types of SIE should make up future energy systems and in what ways and addressing what types of issues. Finally, we argue that the typology presented here can also serve as a heuristic device for identifying and classifying the diversity of social innovation in sectors other than energy (Table 1), and invite future empirical research in this direction.

Declaration of competing interest

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